Task 1 – Energy and Energy Spectral Density

The following steps can be used to find the energy spectral density of a signal ‘x’ using MATLAB:

1. Define N = length(x)
2. Use fft(x)/fs to compute normalize fft of the signal.
3. The above function gives the Fourier transform of the signal, which is not centered at the zero frequency. In order to move the zero frequency component to the Enter center, use fftshift( ).
4. The Fourier transform is in complex form. Its magnitude spectrum can be obtained by using the abs(_) function.
5. The energy spectral density is simply the squared amplitude spectrum.
6. The total energy of the signal can be obtained by taking the sum of the energy spectral density and multiplying the result with fs/N.

Exercise 1

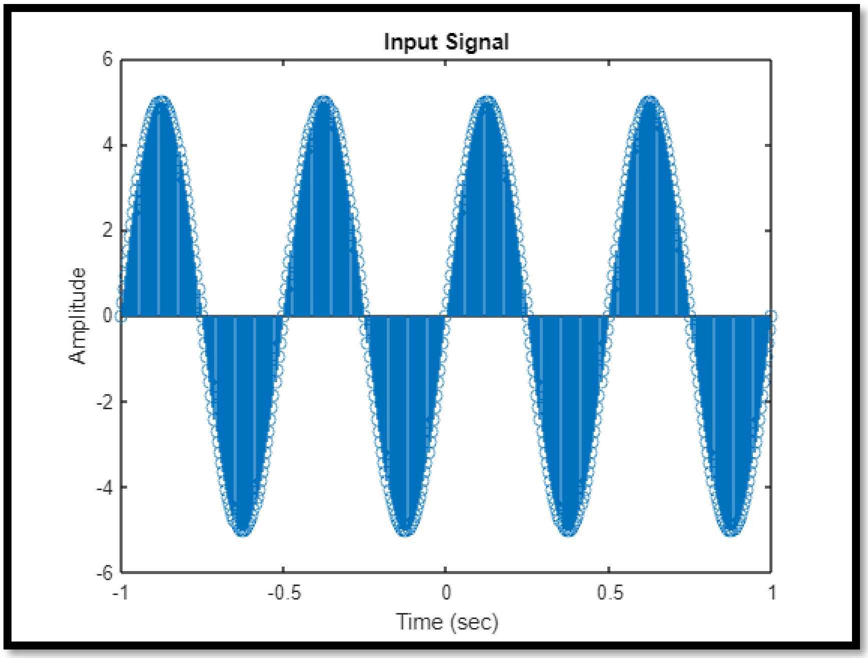
1. Using sampling frequency to be 200, and time increment as 1/fs, generate a sinusoidal signal with amplitude 5 and frequency 2 Hz, between -1 and 1 sec.
2. Add uniform noise using randn function. The resulting signal will be used as input signal. Plot it against time.
3. Write a MATLAB code to compute and plot the energy spectral density of the signal. You can define the frequency vector from (–N/2:N/2-1)*fs/N for the frequency domain plot.
4. What are the frequencies at which most of the energy of the signal is concentrated?

Code:

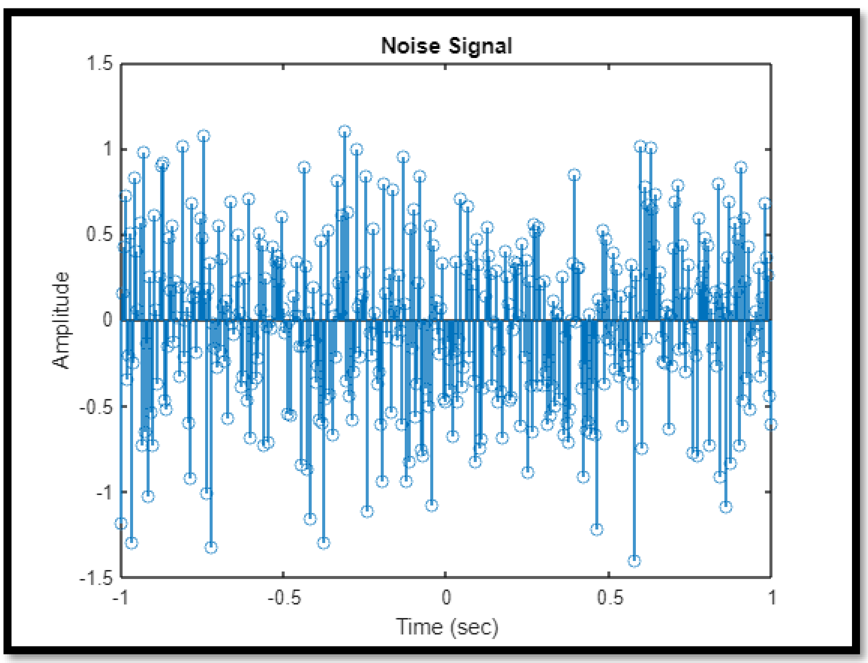
```
% Define sampling frequency and time increment
fs = 200;
dt = 1/fs;

% Define time vector
t = -fs/2:dt:fs/2-dt;

% Generate sinusoidal signal and ploting
x = 5*sin(2*pi*2*t);
stem(t, x);
xlim([-1 1]);
ylim([-6 6]);
xlabel('Time (sec)');
ylabel('Amplitude');
title('Input Signal');
```

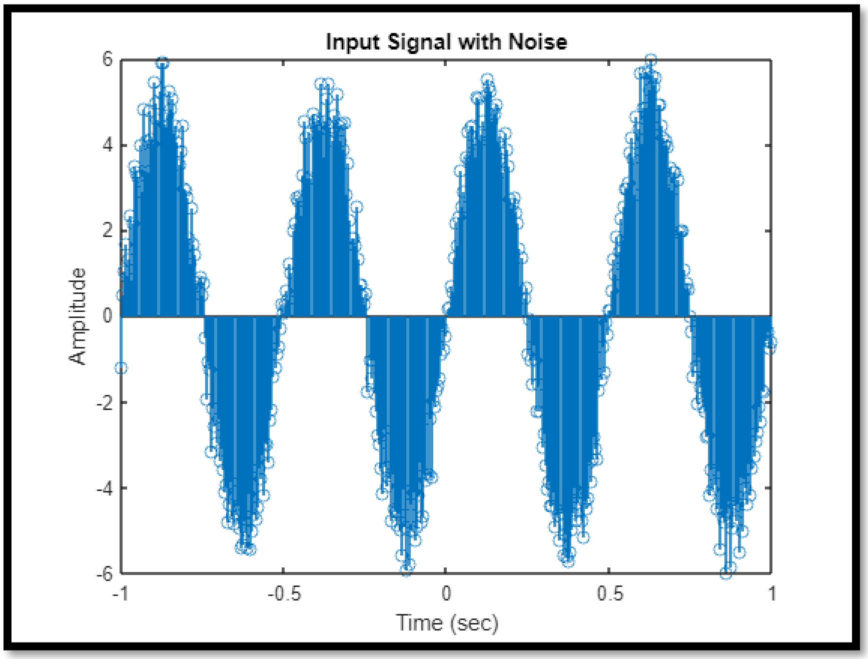



```
% Add uniform noise
noise = 0.5*randn(size(t));
stem(t, noise);
xlim([-1 1]);
xlabel('Time (sec)');
ylabel('Amplitude');
title('Noise Signal');
```

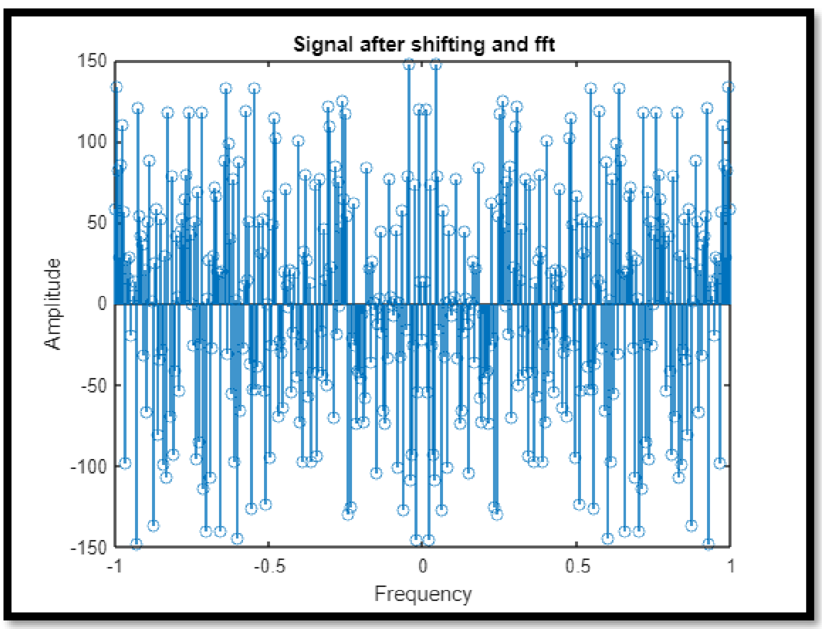



```
%subplot(5,1,3)
x_noise = x + noise;
% Plot signal against time
stem(t, x_noise);
```

```
xlim([-1 1]);
xlabel('Time (sec)');
ylabel('Amplitude');
title('Input Signal with Noise');
```




```
%subplot(5,1,4)
% Compute FFT and shift it
X = fftshift(fft(x_noise));
stem(t, X);
xlim([-1 1]);
xlabel('Frequency');
ylabel('Amplitude');
title('Signal after shifting and fft');
```



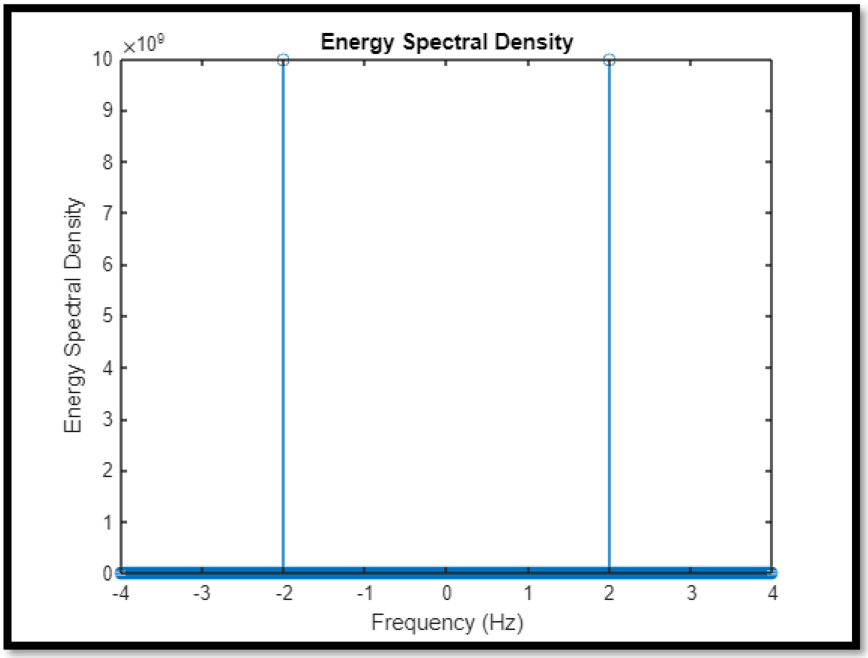
```
% Compute magnitude spectrum
X = abs(X);

% Compute energy spectral density
X = X.^2;

% Compute total energy
total_energy = sum(X)*dt*fs/length(x);

% Compute frequency vector
f = (-length(x)/2:1:length(x)/2-1)*fs/length(x);

% Plot energy spectral density against frequency
%subplot(5,1,5)
stem(f, X);
xlim([-4 4]);
xlabel('Frequency (Hz)');
ylabel('Energy Spectral Density');
title('Energy Spectral Density');
```




```
% Find frequencies at which most of the energy is concentrated
[max_energy, max_index] = max(X);
freqs_of_interest = f(max_index-5:max_index+5);

disp(['Frequencies at which most of the energy is concentrated: ',
num2str(freqs_of_interest)]);
```

```
Frequencies at which most of the energy is concentrated: -2.025       -2.02       -2.015        -2.01
-2.005          -2       -1.995        -1.99       -1.985        -1.98       -1.975
```

Explanation:

I analyzed a noisy signal in MATLAB. First, I defined the sampling frequency and the time increment. Then, I created a time vector ranging from negative half of the sampling frequency to just before the positive half. Next, I generated a sinusoidal signal and added uniform noise to it. The resulting signal was plotted against time. Afterward, I computed the Fast Fourier Transform (FFT) of the noisy signal and shifted it. The magnitude spectrum was calculated, and the energy spectral density was obtained by squaring the magnitude. The total energy of the signal was also computed. Finally, I identified the frequencies at which most of the energy was concentrated. These frequencies were determined by finding the maximum energy values in the spectrum and examining the corresponding frequency bins. The results were displayed in the console. In summary, I analyzed the input signal with noise, computed its energy spectral density, and identified significant frequency components.

Exercise 2

- Find the total energy of the signal by taking the sum of the square of its value at each time instant and multiplying the final result with the time increment.
- Find the total energy of the signal again by taking the sum of the energy spectral density and multiplying the final result with fs/N. Compare the two results.

Code

```
% Define sampling frequency and time increment
fs = 200;
dt = 1/fs;

% Define time vector
t = -fs/2:dt:fs/2-dt;

% Generate sinusoidal signal
x = 5*sin(2*pi*2*t);

% Add uniform noise
x = x + 0.5*randn(size(t));

% Compute energy of the signal at each time instant
energy_at_time = sum(x.^2)*dt;

% Compute total energy of the signal
total_energy = sum(energy_at_time)*dt;
```

```
% Compute FFT and shift it
X = fftshift(fft(x));

% Compute magnitude spectrum
X = abs(X);

% Compute energy spectral density
X = X.^2;

% Compute total energy of the signal using energy spectral density
total_energy_from_spectrum = sum(X)*fs/length(x);

% Compare the two results
disp(['Total energy of the signal computed using energy spectral density: ',
num2str(total_energy_from_spectrum)]);
```

```
Total energy of the signal computed using energy spectral density: 12.739
```

```
disp(['Total energy of the signal computed using energy at each time instant: ',
num2str(total_energy)]);
```

```
Total energy of the signal computed using energy at each time instant: 12.728
```

Explanation:

In this MATLAB code, I defined the sampling frequency and generated a sinusoidal signal with added uniform noise. I then computed the energy of the signal at each time instant and the total energy. Next, I performed the FFT and obtained the magnitude spectrum and energy spectral density. Finally, I compared the total energy computed using the energy spectral density with the total energy computed using the energy at each time instant.

Task 2 – Power Spectral Density

The following steps can be used to find the energy spectral density of a signal 'x' using MATLAB:

1. Define N = length(x)

2. Find the average power of the signal.

3. Find the Powerspectral density of signal by using pspectrum command.

Exercise 3

The signal y(t) is defined as below. This signal is sampled at 1000 samples per second.

$$y(t) = \begin{cases} \cos(2\pi \times 47t) + \cos(2\pi \times 219t) & ; \quad 0 \le t \le 10 \\ 0 & ; \quad \text{otherwise} \end{cases}$$

1. Plot the time domain signal y(t).
2. Find the power spectral density of this signal.

Change the frequencies of cosines as 100 Hz and 250 Hz and explain the difference.

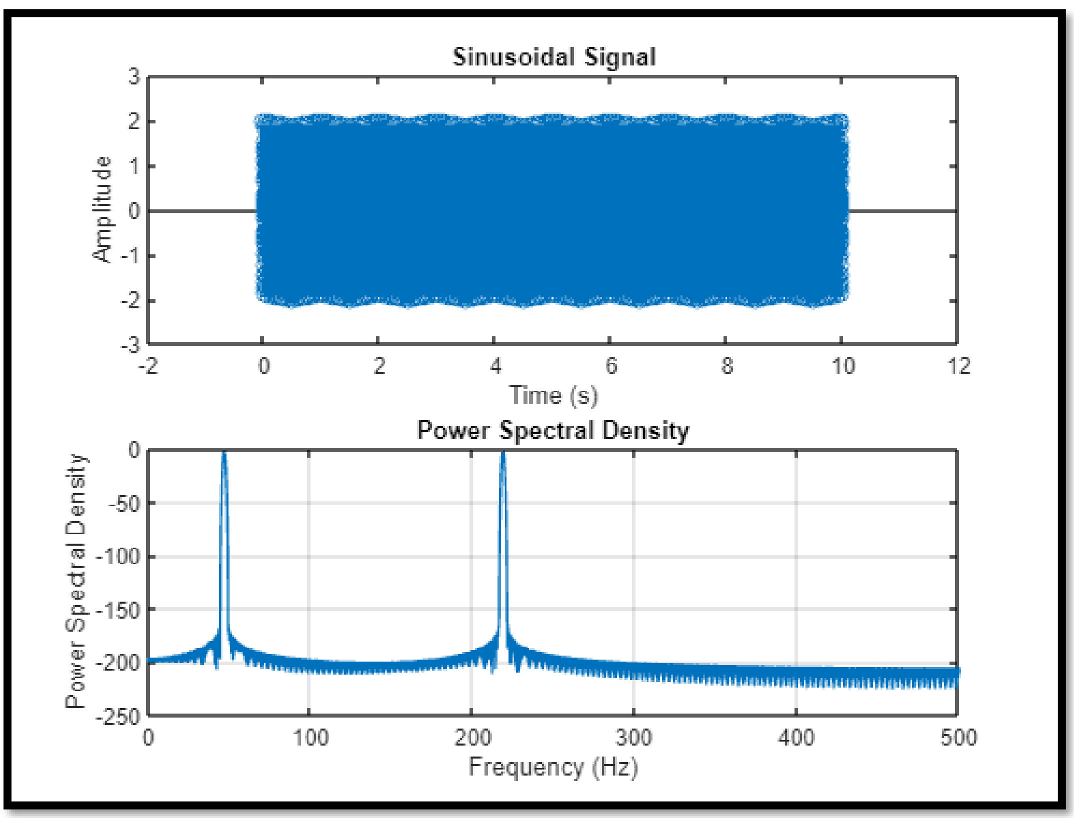
code

```
Fs = 1000; % Sampling frequency
t = 0:1/Fs:10;
y = cos(2*pi*47*t) + cos(2*pi*219*t);
N = length(y);
P = (norm(y)^2) / N
```

```
P = 1.0003
```

```
figure;
subplot(2,1,1);
stem(t, y);
axis([-2 12 -3 3]);
title('Sinusoidal Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(2,1,2);
pspectrum(y, Fs);
title('Power Spectral Density');
xlabel('Frequency (Hz)');
ylabel('Power Spectral Density');
```



Explanation:

In this MATLAB code, I created a sinusoidal signal by combining two cosine waves. I computed the power of the signal and visualized it using a stem plot. Additionally, I plotted the power spectral density of the signal to show its power distribution across different frequencies.

Conclusion:

In this Communication lab, I defined sampling frequencies, generated signals, added noise, and performed signal processing operations. I computed energy and power, analyzed signals in the time and frequency domains, and visualized the results. By utilizing various techniques such as the Fast Fourier Transform, I gained insights into the signals' characteristics. These codes allowed me to explore and understand the behavior of the signals and their energy distribution.